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ABSTRACT

The cognitive processing strategies of two groups of French-English bilinguals were studied by means of an auditory Stroop test designed to evaluate cerebral hemispheric involvement. An "early bilingual" group were bilingual before the age of five, and a "late bilingual" group were bilingual after the age of ten. Stimuli were words uttered in pitches that were related to word meanings either congruently (as in the word "high" uttered in a high pitch) or incongruently (the word "haute" uttered in a low pitch). In one condition, subjects were to differentiate low from high pitches, disregarding meaning, while in a second condition, they were to disregard pitch and respond to word meanings. Measures of field independence were also taken. Results of data analyses suggest that male early bilinguals, the most field independent subgroup, process meaning efficiently in both cerebral hemispheres, but they process pitch better in the right hemisphere. However, male late bilinguals and female bilinguals, both early and late, process meaning more efficiently in the right cerebral hemisphere and process pitch in both hemispheres. The findings are interpreted as reflecting hemisphere-based strategy and sex differences in information-processing by the two bilingual groups. (Author/CFM)

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Cerebral Involvement in the Cognitive Functioning of Bilinguals

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Abstract

The cognitive processing strategies of two groups of French-English bilingualswere studied by means of an auditory Stroop test designed to evaluate cerebral hemispheric involvement. An "early bilingual" group were bilingual before the age of five, and a "late bilingual" group were bilingual after the age of ten. Stimuli were words uttered in pitches that were related to word meanings either congruently (as in the word "high" uttered in a high pitch) or incongruently (the word "haute" uttered in a low pitch). In one condition, subjects were to differentiate low from high pitches, disregarding meaning, while in a second condition, they were to disregard pitch and respond to word meanings. Measures of field independence were also taken.

Results of data analyses suggest that male early bilinguals--the most field independent subgroup--process meaning efficiently in both cerebral hemispheres, but process pitch better in the right hemisphere. However, male late bilinguals and female bilinguals, both early and late, process meaning more efficiently in the right cerebral hemisphere and proces pitch in both hemispheres.

The findings are interpreted as reflecting hemisphere-based strategy and sex differences in information-processing by the two bilingual groups.

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Cerebral Involvement in the Cognitive Functioning of Bilinguals

Jyotsna Vaid and Wallace E. Lambert

Considerable evidence for cerebral hemispheric specialization of function has been gathered through both clinical and experimental work (Bakker, 1970; Berlin & McNeill, 1976; Dennis & Kohn, 1975; McKeever & Huling, 1971; Milner, 1975; Neville, 1974; Sperry, 1975; Witelson, 1976). Taken together, the diverse sources of evidence for the existence of hemispheric differences support the view that the left cerebral hemisphere is more efficient in tasks involving linguistic skills, while the right hemisphere is more efficient in tasks involving visuospatial skills. This pattern of differences typically characterizes strongly right-handed individuals, while non-right-handers show a less consistent pattern (Hecaen & Sauget, 1971). Recent evidence suggests that this standard pattern of neural organization is more characteristic of males than females, and that females typically show less marked functional asymmetries (Andrews, 1977; Buffery, 1971; Lake & Bryden, 1976; McGlone, Note 1).

Evidence in the past decade has led to a revision in the concept of lateralization of function. The traditional view, based largely on studies of patients with unilateral brain lesions (Milner, 1975), emphasized features intrinsic to the stimuli as being responsible for the observed behavioral

asymmetries. A more recent alternative has been proposed in terms of separate information-processing systems that are not automatically triggered by the characteristics of the stimulus input. According to this view, the features intrinsic to stimuli do not determine hemispheric differences per se so much as the use one makes of these features (Bartholomeus, 1974; Bever, 1975; VanLancker & Fromkin, 1973). The emphasis is directed more to the modes of information processing occurring in the two hemispheres and less to the characteristics of the stimuli presented to the two sides. Hence, the left hemisphere is regarded as being better at processing information analytically and propositionally while the right hemisphere is better at processing information in a wholistic and appositional mode (Levy-Agresti & Sperry, 1968; Bogen, 1969).

Work on cerebral lateralization has dealt almost exclusively with speakers of a single language. The present study raises the question of lateralization in bilinguals. To the extent that experiential factors influence laterality (cf. Geffner & Hochberg, 1971; Bever, Note 2), bilingualism, representing an enriched form of language experience, may have an important influence on hemispheric specialization. Lateralization in bilinguals is, moreover, of general theoretical significance insofar as it bears on the relationship between neurological and language development (cf. Lenneberg, 1967; Krashen, 1973; Segalowitz & Gruber, 1977) and on the role of the right hemisphere in language learning and use (cf. Curtiss, 1977;

Moscovitch, 1976; Searleman, 1977; Zaidel, 1977).

Clinical studies. The literature on aphasia in speakers of more than one language is replete with cases of differential loss or recovery of one or more of the languages the aphasia patients spoke prior to the trauma (Gloning & Gloning, 1965; Lebrun, 1976; Leischner, 1948; Minkowski, 1963; Nair & Virmani, 1973; Galloway, Note 3; see Paradis, 1977, for a review). This has led to the speculation that the languages of the bilingual or multilingual are differentially represented in the brain. Speculations of this sort may be premature since, as Charlton (1964) has pointed out, these clinical reports may not represent the norm but rather the unusual and thus the more interesting cases. Moreover, in the absence of proper methodological controls (e.g. handedness, premorbid linguistic fluency and usage), insights gleaned from such clinical reports have a heuristic value at best.

Experimental studies. The findings of recent experimental studies of lateralization in bilinguals (reviewed in Vaid, Note 4) are also inconclusive. While some studies (e.g. Hamers & Lambert, 1977; Bellisle, Note 5; Walters & Zatorre, Note 6) report for both languages of bilingual subjects a pattern of functional asymmetry comparable to that noted in unilinguals, other studies report a differential pattern of asymmetry within bilingual groups across their two languages (e.g. Rogers, TenHouten, Kaplan & Gardiner, 1976; Obler, Albert & Gordon,

Note 7) or between different bilingual groups for both their languages (e.g. Genesee, Hamers, Lambert, Mononen, Seitz & Starck, 1978; Gordon, Note 8). Still others report an absence of significant lateralization differences in either bilinguals or unilinguals (Hardyck, Tzeng & Wang, 1978).

There has been considerable variation from study to study in type of tasks, measures of laterality and subject screening methods. With few exceptions, unilingual controls have not been included, the variable of sex has neither been controlled for nor specifically examined, and very few of the studies have so far been replicated. Thus, it is difficult to arrive at any general conclusions.

The attempt is further complicated by the diversity of theoretical orientations to the problem. Some researchers have focussed on the effect of early multilingual training on degree of lateralization (cf. Starck et al., 1977). Others have focussed on the idiosyncrasies of a particular language of the bilingual and the possibility that these might be conducive to a differential intra- or inter-hemispheric organization (cf. de Agostini, 1977; Hatta, 1977; Luria, 1963; Rogers et al., 1976; Sasanuma, Itoh & Kobayashi, 1977; Tsunoda, 1971). Still others have stressed the process of second language learning, questioning whether the right hemisphere plays an important role during the initial stages of second language learning and whether the left hemisphere assumes control once the individual becomes equally proficient in the two languages (cf. Gaziel,

Obler, Benton & Albert, Note 9; Obler, in press).

Finally, lateralization of bilinguals has been studied in the light of language acquisition histories of bilinguals (cf. Lambert , Havelka & Crosby, 1958). Hartnett (1976) has shown, for example, that mode of instruction in the second language, inductive versus deductive, is correlated with direction of subjects' reflective eye movements, left versus right, respectively. The context of second language acquisition, compound versus coordinate (cf. Ervin & Osgood, 1954), appears to have differential effects in recovery from aphasia (Lambert & Fillenbaum, 1959).

Of the many factors found in language acquisition histories, the age of onset of bilingualism has provided the least equivocal results in behavioral studies (Genesee, 1977). Bilinguals who acquired their second language at infancy appear to employ a different strategy in processing verbal material than that used by bilinguals who acquired their language later in life. "Early" bilinguals, for example, were found to be more adept at arriving at a core concept through the use of mixed-language verbal cues (Lambert & Rawlings, 1969). Early bilinguals were less able than late bilinguals to set aside the distracting meanings of bilingual Stroop stimuli (Lambert, 1969).

More recently, early bilinguals (classified as "infant" and "child" bilinguals) were shown to have a faster averaged evoked response (AER) to the N_1 peak in the left cerebral hemisphere for both languages during a monaurally presented

language recognition task. Late bilinguals (referred to as "adolescent" bilinguals), carefully measured to be balanced in skills in the two languages[2], showed a faster AER latency to the N_1 peak in the right cerebral hemisphere for both languages (Genesee et al., 1978).

Thus, behavioral and neurobehavioral studies have provided support for a distinction between groups of bilinguals on the basis of age of onset of bilingualism. The difference appears to be reflected in the language processing strategy adopted by the two groups: those who became bilingual at infancy or in early childhood appear to use an analytic, semantic approach to verbal material. In contrast, those bilinguals who acquired their second language during adolescence or thereafter tend to adopt a different approach to verbal material, one that relies more on extralinguistic (e.g., physical) features of the linguistic stimuli.

The present study was designed to investigate cerebral hemispheric involvement in early and late bilinguals during linguistic and nonlinguistic processing using behavioral measures. In addition, the study sought to examine the variable of sex in the context of lateralization in bilinguals, and to compare bilinguals with unilinguals.

Insofar as the Stroop test (cf. Stroop, 1935) measures interference produced by differences in the speed or efficiency of processing two competing aspects of stimuli (Morton, 1969; Glaser & Dolt, 1977; Seymour 1977), it is an especially useful

method of assessing lateralization. Studies of lateralization using the Stroop paradigm, although few in number and relatively recent (Cohen & Martin, 1975; Dyer, 1973; Schmit & Davis, 1974) allow one to assess the relative efficiency with which each aspect of the stimulus is processed by the two hemispheres.

The paradigm employed in the present study was a monaurally presented auditory Stroop test adapted for bilinguals (Hamers & Lambert, 1972). In addition to the classic auditory Stroop test (cf. Cohen & Martin, 1975) where the task is to attend and respond solely to the pitch of the stimuli disregarding the meanings involved, a reversed Stroop test (cf. Shor, 1975) was also incorporated into the design. For the reversed Stroop test, the required task is to attend and respond to the meaning of the words presented, ignoring the pitch in which they are said. By studying performance on both the classic auditory Stroop test (henceforth to be referred to as the PITCH condition) and the reversed Stroop (the MEANING condition), a more thorough appraisal of hemispheric lateralization in bilinguals is possible, since both verbal and nonverbal processing strategies can be evaluated.

For purposes of comparison and control, tests were also made with pure tones in order to ensure that the groups had comparable reaction times to auditory stimuli at the outset.

It seemed valuable to search out a separate measure of laterality in order to validate the findings on the Stroop test. The Embedded Figures Test (Witkin, Dyk, Faterson,

Goodenough & Karp, 1962) was chosen because previous studies have shown a correlation between field independence and laterality in both clinical (Gordon & Tikofsky, 1961; Pizzamiglio & Carli, 1974; Russo & Vignolo, 1967) and normal (Oltman & Capobianco, 1967; Pizzamiglio, 1974) populations. No one, so far, has looked at field independence in the context of lateralization in bilinguals, even though studies on bilinguals suggest that relative to unilinguals, the former are cognitively more flexible (Peal & Lambert, 1962; Lambert, 1969; Segalowitz, 1976; Cummins, 1976). One might therefore expect that since the demands are great on bilinguals to differentiate and keep separate two linguistic systems, they may become more field independent than unilinguals (cf. Cohen, 1977; Defazio, 1973; Tucker, Hamayan & Genesee, 1976).

Certain predictions were, accordingly, made at the start of the experiment:

1) There should be no group differences in reaction time to pure tones, if there are no build-in biases of bilinguality on perceptivity of this type.

2a) English unilinguals should show a greater right ear (RE) interference in the PITCH condition wherein they are asked to respond to the pitch and ignore the meaning of the words presented, for in this case it would be difficult to bypass the meaning of words in their own language arriving at the left hemisphere (cf. Cohen & Martin, 1975). In the MEANING condition when they are required to respond to the meaning of the stimulus

and to ignore its pitch, the control subjects should show a greater interference from the pitch of stimuli coming through the left ear (LE) since the left ear-right hemisphere route is presumably more efficient in pitch analysis (Blumstein & Cooper, 1974; Kallman & Corballis, 1975).

2b) Early bilinguals, if their preferred strategy is primarily semantic, should have difficulty in ignoring the meanings of stimuli presented either to the right or the left ear in the PITCH condition. In the MEANING condition, early bilinguals should show greater interference from pitch for stimuli entering through the left ear, for the same reason that one would expect a left ear interference in the unilinguals in the condition (cf. Blumstein & Cooper, 1974).

2c) Late bilinguals in the PITCH condition should show a greater Stroop interference for the left ear stimuli, to the extent that they have been found to prefer the right hemisphere mode in processing language. If it is true that late bilinguals rely on the right hemisphere for language processing, then in the MEANING condition, language processing would be expected to supersede any effects of pitch processing in the right hemisphere.

3) One would expect sex differences in the amount of interference experienced in each of the experimental conditions and in the

strength of the functional ear asymmetry: Females should be more susceptible than males to interference from semantic processing during the PITCH condition (as suggested by the literature on sex differences in verbal skills, summarized by Maccoby and Jacklin, 1974), and should be less susceptible than males to interference from pitch processing during the MEANING condition (cf. Majeres, 1977). Males should show more pronounced ear differences than females, in both experimental conditions (cf. Johnson & Kozma, 1977).

4) Research on field dependence suggests that females would be more field dependent than males (Witkin & Berry, 1975), and that unilinguals might be more field dependent than bilinguals (cf. Defazio, 1973). Finally, in light of the growing body of research correlating field dependence with lesser lateralization, one might expect that the more field independent individuals would also be the more lateralized (cf. Waber, 1977).

METHOD

Subjects

Subjects were 48 students, ranging between 17 and 29 years of age (mean age = 21.1 yrs). They were placed into three groups. Group 1 consisted of 16 bilinguals fluent in French and English, who had acquired both languages in early childhood--their mean age of second language acquisition was 4.6 years. These subjects were considered "early bilinguals". Group 2 comprised 16 fluent bilinguals whose mean age of second language

acquisition was 10.9 years (for half of the subjects in this group, English was the native language and for the remainder, the reverse was true). These subjects were considered "late bilinguals". Group 3 consisted of 16 English unilinguals.

Within each group there were 8 males and 8 females. All subjects reported no known hearing difficulties. Handedness of subjects was assessed by means of a detailed questionnaire adapted from Oldfield (1971) and Crovitz and Zener (1975), following the suggestion of Bryden (1977). All subjects were strongly right-handed, with very few instances of left-handedness in their immediate family. A detailed account of their language acquisition histories, and the context of current language usage was obtained from each subject[3].

Fluency in their two languages was assessed in the bilinguals by the following measures:

1) self-evaluation by the bilingual of proficiency in speech, reading, writing, and general comprehension in the two languages.
2) speed in reading aloud a series of colored patches in each of the two languages (cf. Lambert, 1969).
3) judgment of native-like pronunciation in each of the languages by the bilingual experimenter, while the subject read aloud in the color-naming task.

The bilinguals were largely students at McGill University, Montreal, while most of the unilinguals were students at the State University of New York at Potsdam, since English uni-

linguals with no experience with French were difficult to find in Montreal.

Materials

The three minute standard version of the Embedded Figures Test, Form A, was used as a measure of field dependence. Time taken to discover the hidden figures was measured to the nearest tenth of a second by means of a Westclox stop watch.

The stimuli for the auditory Stroop experiment consisted of the taped words high and low and their French, feminine, equivalents, haute and basse, (cf. Hamers and Lambert, 1972) pronounced by a female bilingual fluent in the two languages. A Sony 2-channel TC-270 tape recorder was used to record and present the stimuli.

Each of the words was recorded in a high pitched voice (of approximately 300 Hz.), and in a low pitched voice (200 Hz.) making a total of 8 possible stimuli: $\underline{high}_{H}$, $\underline{low}_{L}$, $\underline{haute}_{H}$, $\underline{basse}_{L}$ (constituting the congruent cases) and $\underline{high}_{L}$, $\underline{low}_{H}$, $\underline{haute}_{L}$, $\underline{basse}_{H}$ (comprising the incongruent cases).

In addition to the experimental stimuli, pure tones in high and low frequencies (300 Hz. and 200 Hz., respectively) were also presented to half of the subjects in each group to determine whether general reaction time differences existed for the various subgroups.

The experimental and control stimuli were approximately one second in duration, and were presented with 5-second inter-trial-intervals. A voice-operated relay (Model E7, 300A-1)

connected the tape recorder to a multichoice reaction timer (Lafayette 63010), which measured manual reaction time in hundredths of a second.

Procedure

Subjects were tested individually in a quiet room. They were each first asked to fill out a questionnaire concerning language background and hand preference. The bilinguals were also tested on color naming speed in French and English. The embedded figures test was then administered, after which the experiment proper was initiated.

All subjects were instructed, in English, to respond selectively to the pitch, or to the meaning of the verbal stimuli which were presented monaurally through stereophonic headphones (Miida, HP-5). English unilinguals were told the meanings of the French stimuli, and were otherwise given identical instructions.

Headset position was counterbalanced, such that half of the subjects heard the stimuli from the right channel in the right ear, and the other half had their headphones reversed. Stimuli were presented in blocks for each ear and experimental condition. Each of the 8 Stroop stimuli was presented twice to each ear, with language of stimulus randomized. The high and low pure tones were each presented four times to each ear, in a randomized sequence. The pure tones were presented as a block preceding and following the Stroop stimuli.

Mode of response was manual and all subjects were instructed to use only their right index finger in pressing a designated response key. Reaction times for accurate responses were measured in hundredths of a second and a score was obtained for each trial.

RESULTS

Auditory Stroop Test

The analysis of the reaction time (RT) scores in the pure tone condition revealed a significant main effect of Sex, $F(1,18) = 5.93, p < .05$, indicating that males were faster in responding to the tones than females (mean RTs were 42.4 and 57.0 hundredths of a second, respectively). There were no significant group differences.

Two separate analyses of variance[4] were performed on the RT scores obtained for the two experimental conditions: PITCH and MEANING. The factors in each analysis were Group (G_1 = Early bilinguals, G_2 = Late bilinguals, G_3 = English unilinguals). Sex (X_1 = Females, X_2 = Males), Ear (E_1 = left ear, E_2 = right ear), Language (L_1 = English, L_2 = French), Congruency (C_1 = Incongruent, C_2 = Congruent stimuli), Stimulus type (H_1 = low pitched words, H_2 = high pitched words, in the PITCH condition; in the MEANING condition, H_1 designated the words *low* and *basse*, H_2 the words *high* and *haute*). Subjects were nested on Group and Sex with repeated measures on the remaining four factors.

Results of the PITCH analysis

Main effects. In the PITCH condition, the task was to attend and respond solely to the pitch of the words presented. The analysis of variance revealed strong main effects for Congruency ($F(1,42) = 96.03$, $p < .001$) and for Stimulus type ($F(1,42) = 41.13$, $p < .001$).

Interaction effects. Significant higher order interactions (LC, LCH, XCH) involving these two factors, however, restrict the generality of the main effects in the following way: While the Congruency effect indicated that incongruent stimuli produced longer mean reaction times than congruent stimuli, the effect was found to hold true for the English words more so than for the French words. More specifically, while the Stroop effect (differences in RT between incongruent and congruent stimuli) was significant for the English words in both high and low pitches (i.e., $\underline{high}_L$ and $\underline{low}_H$ produced longer mean RTs than $\underline{low}_L$ and $\underline{high}_H$, respectively), it was significant for the French words only when they were presented in a low pitch (i.e., $\underline{haute}_L$ produced a longer RT than $\underline{basse}_L$). For high-pitched French words, RT to the incongruent form ($\underline{basse}_H$) was, in fact, faster ($F(1,84) = 4.50$, $p < .05$) than that to the congruent form ($\underline{haute}_H$), suggesting a disparity between the perceived similarity and surface congruency of pitch and meaning of the stimulus. This somewhat paradoxical finding may perhaps be attributable to the fact that in normal usage, haute is uttered in a lower pitch than is its English equivalent, high, which, by aid of

the vowel "i", connotes precisely what it denotes (cf. the literature on phonetic symbolism, summarized in Taylor, 1976). Hence, in the Stroop situation, changing the pitch is disruptive in the incongruent case ($\underline{high}_L$) and facilitative when congruent ($\underline{high}_H$) whereas doing so in the former case ($\underline{haute}_L$) is disruptive when the pitch conflicts with the meaning, but not particularly facilitative when the pitch corresponds to the meaning (as in $\underline{haute}_H$).

A breakdown of the Sex x Congruency x Stimulus type (XCH) interaction into simple effects revealed that males responded faster to congruent stimuli when they were said in a high pitch as compared to when they were said in a low pitch ($\underline{F}(1,66) = 4.16$, $\underline{p} < .05$), i.e., they responded faster to $\underline{high}_H$ or $\underline{haute}_H$ than to $\underline{low}_L$ or $\underline{basse}_L$. This may have arisen from the fact that the stimuli had been pronounced by a female voice, hence making the high pitched stimuli more salient for the males.

A priori analysis of GXEC. Since there were no other significant findings in the PITCH condition, an a priori analysis of the Group x Sex x Ear x Congruency (GXEC) interaction was undertaken to allow a comparison between the predicted and actual outcomes. Table 1 summarizes the means per group and sex as a function of congruency and ear. The single degree of freedom (d.f.) comparisons revealed the following findings:

1. Both male ($\underline{F}(1,82) = 6.99$) and female ($\underline{F}(1,82) = 7.97$) unilinguals showed a strong RE effect of Congruency ($\underline{p} < .01$). Female unilinguals in addition showed a LE Stroop effect

($F(1,82) = 4.94$, $p < .05$).

2. Male early bilinguals showed a significant Stroop effect in both the RE and LE ($F(1,82) = 6.84$, $p < .025$ and $F(1,82) = 9.78$, $p < .01$, respectively). Female early bilinguals showed a significant Stroop effect in the LE only ($F(1,82) = 5.21$, $p < .025$).

3. Late bilinguals showed a significant Stroop effect in the LE only. This result occurred for both males ($F(1,82) = 4.66$, $p < .05$) and for females ($F(1,82) = 5.47$, $p < .025$).

(Insert Table 1 about here)

Results of the MEANING condition[6]

Main Effects. In the Meaning condition, it will be recalled, the task was to respond only to the meaning of the Stroop stimuli, disregarding the pitch in which they were said. The analysis of variance results revealed two significant main effects--that of Congruency ($F(1,42) = 21.62$, $p < .001$), and Stimulus type, ($F(1,42) = 19.65$, $p < .001$).

Interaction effects. Both effects however, must be qualified in light of significant interaction effects (EC, XLC, and LH), which, when analyzed further, revealed the following:

A significant Stroop effect was demonstrated only for stimuli entering the LE, thereby implicating the right hemisphere in pitch processing ($F(1,42) = 6.29$, $p < .025$). Furthermore, only males showed a significant Stroop effect ($F(1,42) = 14.05$, $p < .001$), and did so only for the English stimuli ($F(1,42) = 26.75$, $p < .001$).

The Language x Stimulus type interaction revealed that subjects took longer to respond to the word low than to the word high, regardless of pitch ($F(1,81) = 56.70$, $p < .001$). There is no evidence, however, to suggest that subjects responded differentially to the French equivalents of these two words.

A priori analysis of GXEC interaction. In the absence of significant group effects for the MEANING condition, an a priori analysis of the GXEC interaction means was undertaken to permit a comparison between the predicted and the observed results. Mean RT scores per group and sex are given in Table 2. The results of the single d.f. comparisons were:

1. Male unilinguals showed a significant effect of Congruency in the LE ($F(1,82) = 15.39$; $p < .001$). Female unilinguals showed no significant Stroop interference for stimuli presented either to the LE or to the RE.
2. A significant LE Stroop effect was also found for male early bilinguals ($F(1,82) = 6.68$, $p < .025$). Female early bilinguals showed no significant Stroop effect in either ear.
3. Late bilinguals, both males and females, showed no significant Stroop effect in either ear.

(Insert Table 2 about here)

Embedded Figures Test (EFT)

Main effects. Results of the analysis of variance performed on the EFT scores revealed a significant main effect for Sex ($F(1,42) = 6.58$; $p < .025$) and Group ($F(2,42) = 4.28$;

$p < .025$). The main effect of Sex indicated that males were faster than females at detecting the embedded figures. The mean detection time for males was 21.2 seconds while that for females was 34.9 seconds.

The results of the simple effects analysis for Group indicated that early bilinguals were significantly faster in detecting the embedded figures than either the unilinguals ($F(1,42) = 8.66$, $p < .01$), or the unilinguals and late bilinguals taken together ($F(1,42) = 7.78$, $p < .01$). The unilinguals when compared to the two bilingual groups were significantly more field dependent, ($F(1,42) = 4.66$, $p < .05$).

A posteriori analysis of GX interaction. In the absence of a Group x Sex interaction, a post hoc comparison of the means of the male early bilingual group vs. those for all other subgroups was conducted using the Scheffé test (See Table 3). The results of this test indicated that male early bilinguals were the fastest at detecting the embedded figures (cf. 12.5 secs. vs. 31.1 secs.), and were therefore more field independent than other subjects ($F(1,42) = 6.75$; $p < .05$; $F_{crit.} = 4.07$).

(Insert Table 3 about here)

DISCUSSION

The findings are, in general, consistent with the predictions. Insofar as reaction time to pure tone control stimuli revealed no significant group effect, the observed group differences in RT to the Stroop stimuli cannot be attributed to inherent group differences in reaction time to auditory stimuli.

The pattern of findings of the present study may, therefore, be best understood as reflecting the interplay of hemispheric differences in information-processing mode, preferred cognitive processing strategy of the two bilingual groups, and sex differences in cognitive strategy and in neural organization.

When the task requires responding to the pitch of the stimuli, interference from their meaning is expected, and does occur. In this condition, both male and female unilinguals showed a significant Stroop effect for stimuli entering the right ear, indicating that meaning is processed more readily in the left hemisphere. This replicates the finding of Cohen and Martin (1975) who used a monaural Stroop test to study lateralization in English unilinguals.

In addition, the present study found a sex difference in the performance of unilinguals during the PITCH condition: females showed a significant Stroop effect for stimuli entering the left ear as well as for those entering the right ear. This finding suggests that females are more strongly inclined than males to process for meaning, and points to the possibility of structural differences in neural organization between males and females, in the direction of a greater asymmetry for males.

Male early bilinguals also experienced significant Stroop interference in the PITCH condition for stimuli presented in the right and in the left ears. This bias towards meaning analysis among early bilinguals has been noted in previous studies (Lambert, 1969; Genesee et al., 1978) which have

characterized the preferred processing strategy of early bilinguals as being primarily semantic. The present study substantiates this portrayal, insofar as it demonstrates that male early bilinguals do prefer a semantic/analytic approach, even when such an approach may hinder performance in a task requiring response to the pitch of verbal stimuli.

There appear to be sex differences in the source of such a strategy, as the performance of the female early bilinguals in the PITCH condition indicates. In contrast to their male counterparts, female early bilinguals showed a significant Stroop effect in the left ear-right hemisphere route only. This raises the intriguing possibility that meaning is processed more efficiently in the right hemisphere for this group.

It was predicted that the performance of late bilinguals in the PITCH condition would be more impaired in the left ear-right hemisphere route, if the right hemisphere is indeed more active for this group during verbal processing (cf. Genesee et al., 1978). This prediction was confirmed, as both male and female late bilinguals showed a significant Stroop effect through the left ear only. As such, the present study provides evidence for the presumed reliance of late bilinguals on the right hemisphere during linguistic processing.

When the task calls for a selective response to the meaning of Stroop stimuli, interference may arise from variations in the pitch in which the stimuli are uttered. Although pitch discrimination does not appear to be strongly lateralized (cf. Gates &

Bradshaw, 1977), a greater right cerebral hemispheric involvement in processing pitch has been noted under certain circumstances (cf. Blumstein & Cooper, 1974).

In the MEANING condition, therefore, a greater interference for stimuli presented to the left ear-right hemisphere was expected and obtained among male unilinguals and male early bilinguals. Male late bilinguals, as predicted, showed no significant Stroop effect in this condition. Females from all groups also failed to show significant Stroop interference in the MEANING condition. This suggests the existence of a sex difference in reactivity to meaning (cf. Maccoby & Jacklin, 1974), whereby females are less susceptible than males to the disruptive influences of incongruent pitch information while responding to the meaning of the stimuli.

Taken together, the observed group and sex differences in the processing of meaning and, to some extent, pitch, suggest the following:

Female unilinguals generally appear to be less lateralized than male unilinguals in both meaning and pitch processing. Bilingualism among females appears to have the effect of shifting the control of meaning analysis further to the right cerebral hemisphere. This reliance on the functioning of the right hemisphere would occur in both early and late female bilinguals.

Bilingualism among males also alters the standard pattern of hemispheric asymmetry, typified by the pattern in male

unilinguals, yet it appears to exert a differential effect. Specifically, early onset of bilingualism may entail some involvement of the right hemisphere in meaning analysis, leaving pitch processing unaffected (i.e. still under right hemisphere control). Late onset of bilingualism, however, may entail a definite shift in meaning processing favoring the right hemisphere which would consequently supersede pitch processing occurring in that hemisphere.

The results of the Embedded Figures Test revealed a strong sex difference, with males being more field independent than females. A sex difference in the same direction has often been noted in the field dependence literature, and has been attributed to eco-cultural, and bio-social factors (Witkin & Berry, 1975; Dawson, 1972; Waber, 1977).

The observed group differences in performance on the EFT (see Table 3) are intriguing in two respects: one is the apparent effect that bilinguality may have in bringing about greater cognitive differentiation, which has interesting implications for the emergence of psychological differentiation. The other is the effect of age of onset of bilingualism in bringing about differences in field dependence.

With regard to the finding that bilinguals are more field independent than unilinguals, it can be argued that bilinguals, by virtue of the effort required to keep their two languages functionally distinct, may have become more sensitive to a variety of input cues, allowing them to achieve a functional

separation (cf. Ben-Zeev, 1977,a,b). As a consequence of the greater demand for differentiation, bilinguals may thus have become better trained than unilinguals at distinguishing figure from ground. Although previous investigations of field dependence, with very few exceptions, have not addressed the effect of bilingualism as a factor in increasing psychological differentiation, the present study suggests that it may be an important factor, along with the other factors in socialization known to influence field dependence (Witkin & Berry, 1975).

The present study not only found a difference between unilinguals and bilinguals in field dependence, but also between early bilinguals and all other groups. The greater field independence noted for early bilinguals, and, in particular, male early bilinguals, could perhaps be attributed to even greater demands for differentiation experienced by early vs. late bilinguals. Indeed, recent research on children has shown field independence to be correlated with success in second language learning (Genesee & Hamayan, Note 10; Naiman, Frohlich, Stern & Todesco, 1977).

Ianco-Worrall (1972) noted that Afrikaan-English bilingual children were more aware of the arbitrary relationship between words and their referents than were their unilingual counterparts. In studying the cognitive processing strategies of Hebrew-English and Spanish-English bilingual children, Ben-Zeev (1977a,b) suggested that bilinguality promotes a greater readiness to attend to structure and to reorganize material, verbal or non-verbal.

Several studies on lateralization in unilinguals have found a correlation between field independence and functional separation of the two hemispheres (Pizzamiglio, 1974; Oltman & Capobianco, 1967). The present study provides some support for such a relationship in that males, who were more field independent, appeared to be more lateralized than females, who were more field dependent. However, whether such a relationship can be posited to hold across the language groups is questionable, since the unilingual males, albeit more lateralized relative to the bilingual groups, were, nevertheless, more field dependent than the latter. It may be that, among bilinguals, field independence does not entail a greater degree of lateralization in the two hemispheres, but, rather, a greater degree of interhemispheric cooperation. In any case, it is too early to arrive at any conclusions about the exact relationship between field independence and cerebral lateralization in bilinguals as such.

General Conclusions

It would appear that age of onset of bilingualism is an important factor influencing not only one's characteristic mode of approach to verbal information, but also the relative degree of involvement of the two cerebral hemispheres. Indeed, the results of this study suggest that the processing strategy

adopted by early versus late bilinguals for both their languages reflects the greater reliance of these groups on the left versus the right hemisphere, respectively. Moreover, the results implicate sex differences in the extent to which a given hemisphere participates in a particular type of processing. Females appear to rely less than males on the left hemisphere in analyzing the meaning of verbal stimuli.

While the results of the present study are suggestive of significant differences in hemispheric involvement between males and females, bilinguals and unilinguals, and between early as compared to late bilinguals, they are by no means conclusive. The generality of the findings needs to be tested with stimuli other than single words, or at least with a larger repertoire of lexical items. The findings need to be replicated, moreover, with other language groups, and examined in different age groups. Since others have found a greater right hemispheric involvement in the second language of bilinguals, the effect of proficiency, as it might interact with onset of bilingualism, should also be explored in detail.

Table 1

Mean Reaction Time Per Group as a Function of Congruency, Ear and Sex in the PITCH Condition

Group[a]	Sex	Left Ear		Right Ear	
		Incongruent	Congruent	Incongruent	Congruent
Early bilinguals	M	51.28	41.33***	52.04	43.72**
	F	55.92	48.66**	54.80	48.81
Late bilinguals	M	49.65	42.78*	44.65	43.77
	F	57.94	50.50**	56.94	51.39
English unilinguals	M	55.65	50.31	54.86	46.45***
	F	56.00	48.93*	59.30	50.32***

Note. The reaction time scores were measured in hundredths of a second.

[a] n = 16 for each group.

* The difference between the mean reaction time to incongruent vs. congruent stimuli is significant at $p < .05$.

** $p < .025$.

*** $p < .01$.

Table 2

Mean Reaction Time Per Group as a Function of Congruency, Ear and Sex in the MEANING Condition

Group[a]	Sex	Left Ear		Right Ear	
		Incongruent	Congruent	Incongruent	Congruent
Early bilinguals	M	55.13	45.14*	48.83	46.71
	F	55.22	49.98	51.47	50.86
Late bilinguals	M	48.71	43.12	51.32	46.34
	F	52.19	49.61	50.92	52.39
English unilinguals	M	58.56	46.43**	54.20	50.34
	F	59.09	53.60	56.88	52.99

Note. The reaction time scores were measured in hundredths of a second.

[a] n = 16 for each group.

* The difference between the mean reaction time to incongruent vs. congruent stimuli is significant at $p < .025$.

** $p < .001$.

Table 3

Mean Performance (in secs.) on Embedded Figures Test as a Function of Group and Sex

	Early bilinguals	Late bilinguals	English unilinguals	Overall Mean
M	12.5	21.6	29.5	21.2
F	22.5	39.3	43.0	34.9
Overall Mean:	17.5	30.4	36.2	

FOOTNOTES

1. The research reported here greatly benefitted from the suggestions and critical comments of members of the McGill Brain and Language Seminar group.

2. Like the study of Genesee et al. (1978), the present study sought to investigate hemispheric differences in bilinguals who were equally proficient in both languages, and who differed only in age of onset of bilingualism. Previous studies (e.g. Obler et al., Note 7; Gordon, Note 10) have tended to confound second language proficiency with age of second language acquisition.

3. Copies of the language background and handedness questionnaire administered are available from the authors.

4. In light of the complexity of the experimental design, and consequently the inability of the computer program (BMD-08V) to handle more than 7 factors in the ANOVA, separate analyses for each experimental condition were therefore performed.

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